# High Resolution Electron-Induced XUV Fluorescence for Life Detection

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The most direct evidence for life on other planets would be to detect organic material, but this can be destroyed by environmental degradation within a few tens of millions of years. In contrast to organic substances, mineral fossil evidence can survive for several billion years. Our goal is, therefore, to determine how to recognize the mineralogical traces of life that could be in extraterrestrial rocks.

The Viking and Pathfinder missions have shown that Fe and Mn exist in a number of oxidation states on the Martian surface, for example, FeO, $Fe_2O_3$, $Fe_3O_4$, MnO, $MnO_2$, or $Mn_2O_3$. Minerals formed by bacteria that metabolise Fe and Mn (by redox processes) in such molecules differ from similar minerals formed through chemical weathering. In particular, a steeper gradient in the spatial distribution of the charge states of the constituent ions $Fe^{q+}$ or $Mn^{q+}$ (q = 1, 2, …) than typical of a non-biological mineral would suggest previous biological processes. The energy dispersive hard X-ray fluorescence technique, for example, has been widely used to determine elemental composition, but it cannot distinguish between the different charge states $Fe^{q+}$ or $Mn^{q+}$. We have therefore developed a soft X-ray (XUV) emission experiment to determine the spatial distribution of the oxidation states, which thus makes possible the search for new evidence of life.

In the experiment, we bombard the sample with energetic electrons (1-20 keV) and observe the resulting K or L shell fine structure emission lines. The energies of the fine structure lines depend on the charge of the metal ions $Fe^{q+}$ or $Mn^{q+}$ in the molecule emitting the radiation. It is therefore possible to identify the oxidation state of a mineral by measuring the energies of the K and L shell lines. For example, we show in Fig. 1 the energy shifts of the $L_{2,3}$ ($3d \rightarrow 2p_{1/2,3/2}$) emission lines for different oxidation states of Fe in some background minerals on Mars, where the data was collected at the Lawrence Berkeley Laboratory. We have also found that the oxygen KL emission line ($2p \rightarrow 1s$) of a biological sample (not shown) is narrower than the same line in non-biological minerals. The soft X-ray (XUV) region is thus important in the search for life.

The method is suitable to examine planetary materials returned to Earth from Mars and could be miniaturized to scan samples *in situ* on the planetary surface.

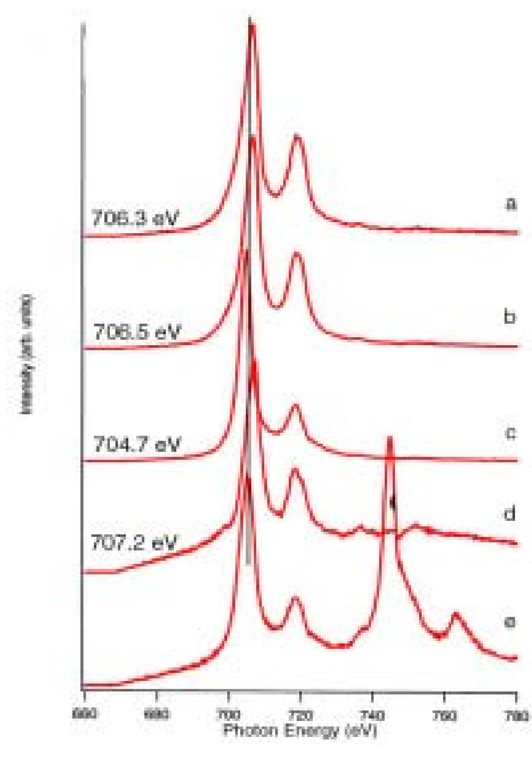


Fig. 1. The $L_{2,3}$ lines of a) $Fe^{3+}{}_2O_3$ (Hematite), b) $Fe^{3+}{}_2Fe^{2+}O_4$ (Magnetite), c) Fe, d) $Mg_{1.6}Fe^{2+}{}_{0.4}(SiO_4)$ (Olivine) and e) Fe and Ni. The energies of the $L_3$ lines are shown.